



## **Risø DTU Annual Report 2010**

Highlights from Risø National Laboratory for Sustainable Energy, DTU

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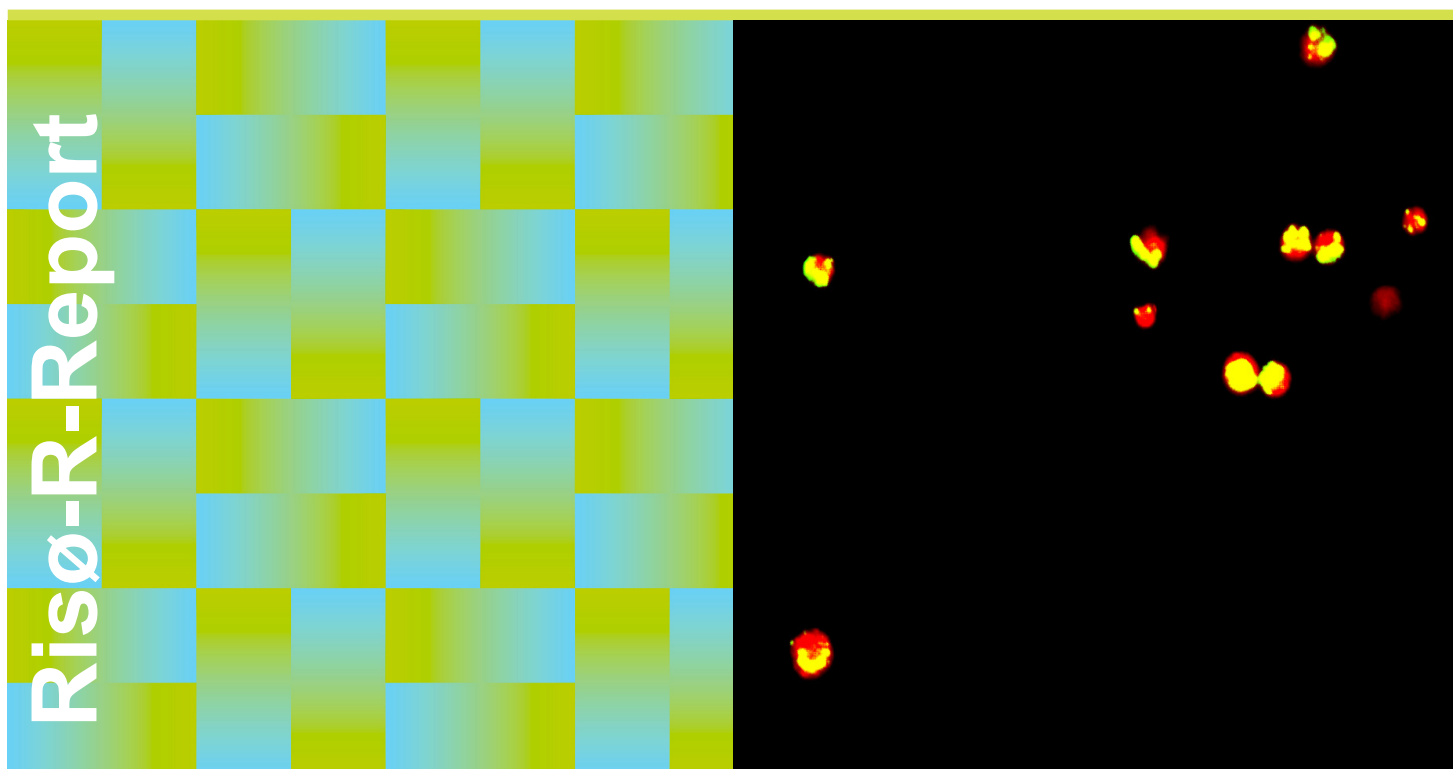
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# Risø DTU Annual Report 2010

Highlights from Risø National Laboratory for Sustainable Energy, DTU



Risø-R-1770(EN)  
August 2011





## Risø DTU Annual Report 2010

### Highlights from Risø National Laboratory for Sustainable Energy, DTU

Edited by Birgit Pedersen and Lars Martiny  
 Risø-R-1770(EN)  
 Risø National Laboratory of Sustainable Energy  
 Technical University of Denmark  
 Roskilde, Denmark  
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Risø DTU unless otherwise stated.

*Picture above shows the avenue of poplars that is Risø DTU's 'main street'. Like the rest of Risø DTU's 262-hectare site, the avenue was laid out by the landscape architect C. Th. Sørensen in 1957 (Risø was inaugurated June 1958).*

*Picture on the front cover shows cells of algae (*Dunaliella salina*) induced to synthesize fat that can be used as biofuel. The cells are stained with the fluorescent substance "nile red" and illuminated with UV light. The red colour is due to fluorescence from chlorophyll a. The yellow colour is due to fluorescence from fat droplets.*

# Risø DTU Annual Report 2010

## Highlights from Risø National Laboratory for Sustainable Energy, DTU

Edited by Birgit Pedersen and Lars Martiny

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*Bent Sørensen successfully defends his DSc thesis on "Cohesive laws for assessment of materials failure: Theory, experimental methods and application", 12 November 2010.*



*As a new initiative in 2010, the Risø Energy Day was held on November 10th 2010. The theme was "A non-fossil energy system in 2050 and beyond". The event attracted about 190 participants from the energy industry, financial institutions, government bodies, embassies and NGOs.*



*In connection with EXPO2010 in China, Risø DTU coordinates a seminar on sustainable energy. The seminar is part of "Better Research, Better Life", organised by the Danish-Chinese Business Forum. The seminar stresses the importance of interaction among scientists, the industry, and the politician.*



*21 – 29 October 2010 Risø DTU hosts the Third International Summit on Organic Photovoltaic Stability. Before and after the ISOS-3 conference, experimental workshops are held where researchers can test their own active ingredients for polymer solar cells in Risø DTU's large-scale production equipment.*


 The logo for BigScience.dk features three orange curved lines above the text "BigScience.dk" in a blue sans-serif font.

*Competition among companies for contracts to develop large European research infrastructures is fierce. The Big Science Secretariat (BSS) assist Danish companies to gain a stake in the profitable contracts. The project secretariat will be located at Risø DTU and is supported by the Danish Agency for Science, Technology and Innovation.*



*"Risø Park" is the working title for Roskilde Municipality's project aiming at establishing a business development park for cleantech, closely connected to Risø DTU. December 16th 2010, ideas were presented on how it could look like, e.g. converting Risø DTU's water tower into a modern landmark.*

## Preface

**"Risø DTU contributes to research, development and international exploitation of sustainable energy technologies, and strengthens economic development in Denmark"**

Global access to adequate energy resources, reduction of greenhouse gas emissions and mitigation of the consequences of global warming continue to be high on the local and global political agendas. Despite hard work and good intentions it has been difficult to achieve a global approach to the challenges, but many national governments today see the development of sustainable technologies and cleantech as means to initiate a new green growth agenda in the aftermath of the recent economic crises.

At Risø DTU we continue to do research in, develop and implement new sustainable energy technologies in close collaboration with other universities, industry and authorities, to provide new solutions to these global challenges. In the following pages you will find an extract of our efforts and results in 2010. I believe you will find them interesting and relevant, and I would like to invite you to visit our webpage or to contact us for more information.



Lars Martiny  
Deputy Director





## Wind energy - a visionary match

Risø DTU develops wind energy through research and innovation in key areas such as meteorology, wind turbine technology, offshore wind energy, power system integration and materials. In addition we are involved in test and measurements, standards and certification, and training.

### Wind turbine aerodynamics with strong inflow shear and wake operation

Advanced flow models have been used to investigate the influence of a highly sheared inflow on the power production and aerodynamics of wind turbines. Analytical analysis and actuator disc simulations predicted an increase in power production compared to fundamental 1D momentum theory. These results were supported by full rotor simulations on a modern turbine. The mechanism thought to be responsible for the increase in power production is a vertical velocity component, which diverts high velocity fluid from the upper part of the inflow downwards through the rotor disc, which thus locally increases the power production compared to the 1D theory.

In practice the implication of this result is that the power production of wind turbines operating in strong shear can be higher than predicted with design codes. Additional work is planned to investigate whether turbine controllers can be designed to further increase power production in highly stratified flows, which in particular, could be relevant for offshore applications.

The advanced flow simulations have been used additionally to validate an improved aerodynamic model in the state-of-the-art wind turbine aeroelastic code developed at Risø DTU, which results in a very accurate prediction of the aerodynamics when for example a turbine operates in the wake of another turbine; a very common flow situation in large turbine clusters.

### New structures in wind turbine blades make them both lighter and stronger

Risø DTU has designed a new load-bearing box girder, which is what we call the interior of the grand white aerodynamic shell. The load-bearing box girder is the skeleton that gives the blade its strength and flexibility, but unfortunately also increases the weight of the blades. Three patents have been issued which



*In early June 2010, the box girder was delivered at Risø DTU. The construction is designed by Risø DTU and was produced by SSP Technology A/S in close cooperation with Risø DTU.*

means that scientists are able to reduce the thickness of main laminate with up to 40%. In early June, the box girder was delivered at Risø DTU. The construction is designed by Risø DTU and was produced by SSP Technology A/S in close cooperation with Risø DTU.

### Superconducting coils for direct drive wind turbine generators

A series of race track coils based on commercial high temperature superconducting tapes have been produced in the Materials Research Division at Risø DTU and have been installed in a small 5 kW generator in collaboration with DTU Electrical Engineering as part of the Superwind project. The coils contain an inner frame of stainless steel onto which the tape is wound together with a glass fiber tape providing the electrical insulation. Copper blocks are soldered to the two ends of the superconducting tape to form current contacts and the coil is vacuum impregnated with epoxy. The coils have been tested at  $T = -196^{\circ}\text{C}$  immersed in liquid nitrogen and the critical currents

#### JANUARY

15

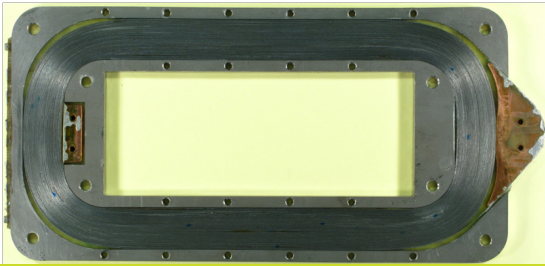
The first Master of Science in Engineering (Sustainable Energy) is graduated from DTU. The MSc program educates experts in various sustainable energy technologies and energy systems.

#### FEBRUARY

22

Frederik Krebs is the Danish project leader of a new Danish-Chinese Center for Organic-based photo-voltaic cells with morphology control. The virtual research center is established by the Danish National Research Foundation and National Natural Science Foundation of China (NSFC).





Race-track coil based on high temperature superconducting tape

determined from finite element modeling have been confirmed. The experimentally obtained properties of the coils have been used as design input for computer models of superconducting direct drive generators for future offshore wind turbines in the 5-10 MW power range. Optimization of the generator topologies and research on cheaper production methods of tapes are ongoing in Materials Research Division at Risø DTU.

### UpWind

UpWind is a European project funded under the EU's Sixth Framework Programme (FP6). The project looks towards the wind power of tomorrow, more precisely towards the design of very large wind turbines (8-10MW), both onshore and offshore. It is the largest-ever funded research and development project on wind energy. UpWind began in 2006 and ends in 2011. It has 43

partners and is coordinated by Risø DTU.

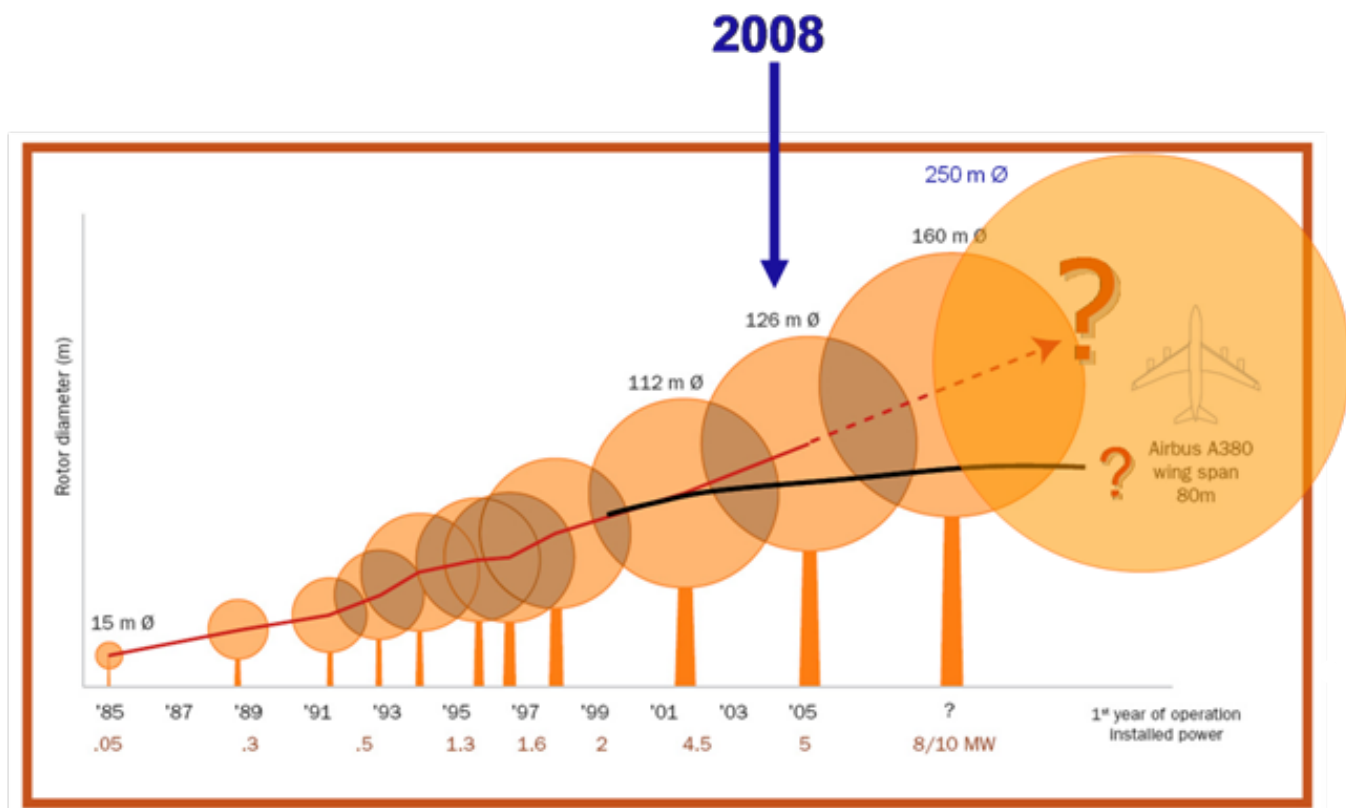
In 2010 UpWind demonstrated that upscaling to a 20 MW design is feasible but also that new innovations should be injected in very large designs to make them economically viable. This illustrates that to develop the very large turbines it is necessary with both long term research and innovations due to the fact that simple upscaling will make the turbines and thereby the wind energy more expensive, and the challenge is to reduce the lifetime cost per kWh.

Many results were harvested in 2010 in many scientific and technical fields e.g. developing the experimental background for applying Lidars, new and more advanced control algorithms, more advanced control features e.g. trailing edge control devices.

In 2010 Risø DTU played a major role in the development of wind farm layouts, and innovative control strategies were developed which for instance is lowering the power output of the first rank to allow higher overall wind farm efficiency. Also Risø DTU did demonstrate the increased need to take the wind shear into account for larger rotors.

UpWind investigated ten different generator configurations and found promising potential weight reductions for permanent magnet transversal flux generators in 2010.

Also, future deeper water locations were investigated and innovative cost-effective designs were developed during 2010.



The UpWind project looks towards the wind power of tomorrow.

MARCH

3

The UNEP Risø Centre on Energy, Climate and Sustainable Development is one of the main organisers of Africa Carbon Forum, held in Nairobi 3 – 5 March. More than 1,000 people from the private and public sector in African and other countries take part in the Forum.

MARCH

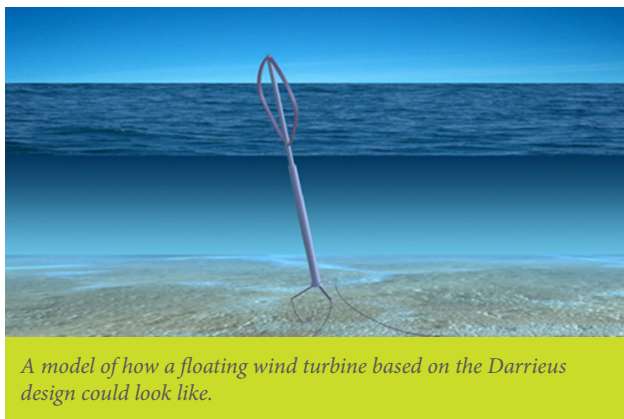
17

A preview of the new Copenhagen Cleantech Cluster (CCC, launched in September 2009) is held at Risø DTU. The event "Tour-de-Risø" is attended by 110 representatives from the business community, researchers and promoters of trade and industry from Denmark and abroad.

## Floating wind turbines in deep water - Deepwind

Floating wind turbines producing at least 20 MW each is the vision that is to be explored in a new collaboration between Risø DTU and international partners from both the industry and the research community. The 4-year project called DeepWind has a €3m grant under the European FP7 programme for future emerging technologies.

DeepWind is the acronym for this new power generation concept and project. The objective is to develop more cost-effective MW wind turbines through dedicated technology rather than advancing existing concepts that are based on onshore technology being transported to the sea environment. Offshore wind energy today is twice as expensive as onshore technologies. That means that there is plenty of room for improvement.



*A model of how a floating wind turbine based on the Darrieus design could look like.*

The basis for the vertical-axis wind turbine is the well-explored Darrieus design. It provides a very simple MW turbine, but is also challenges due to the long sub-sea support structure needed. The concept also includes a direct drive MW generator with its electronic control system at the bottom of the sub-sea shaft, together with the electrical power transmission cables. Combining the relevant technologies and designing the components properly will positively re-address the issues of distribution of cost and the competitiveness of the concept compared to existing technology.

## Optimizing wind farm topology

Traditionally, the layout of a wind farm has at best been optimized with respect to power production. However, a thorough optimization in an economic sense (i.e. lowest cost of energy) requires in addition that the following must taken into account: the load degradation of the wind farm turbines, the financial costs and O&M (operation and maintenance).

This is the main objective of the European project TOPFARM, led by Risø DTU, and through development of the Dynamic Wake Meandering model this has been made possible. The model facilitates both wind farm production and load aspects that both have to be taken into account through detailed aero-elastic computations, and the formulation of a versatile object function. To achieve manageable computation times, the resulting optimization platform is taking advantage of a multi-fidelity approach involving a hierarchy of models of varying complexity and associated CPU requirements. Furthermore, a robust opti-

mization algorithm has been formulated.

Establishment of large wind farms requires enormous investments, and the possibility of conducting a thorough wind farm topology optimization on a rational background is considered a major breakthrough for the future efficient exploitation of on- and offshore wind energy.

An important result so far is that optimum wind farm layout should avoid turbines positioned in straight rows, which is controversial, as nearly all present wind farms have the turbines in rows. The conclusion that is based on the developed simulation method has been supported by measurements conducted in existing wind farms.

## Fast CDF-like solver for the flow in for large wind farms

A detailed model for the flow field in the wake of a wind farm has been developed for estimating loss in large wind farms and in between large wind farms. The model is a linearised model based on the full Navier-stokes equations, but in contrast to the full CFD (Computational Fluid Dynamics) solution this model is approximately 10,000 times faster than the CFD solution giving similar results.

The model consists of new unique mathematical methods for solving linear differential equations, and the model is build into a user-friendly software application named "FUGA". The model has been verified against the wind farms at Hornsrev and Nysted in Denmark showing an excellent agreement.

## Modeling and measurements on the world's first floating combined wind and wave energy plant

In 2010 the world's first combined wind and wave energy platform was launched in the sea north of Lolland, Denmark. It is a floating demonstration platform owned and operated by the Danish company Floating Power Plant A/S. The concept is based on a large rigid triangular floating foundation, which works both as a floating platform for a wave energy concept and three wind turbines.

Risø DTU is project leader of a PSO project "Aero-Hydro-Elastic Simulation Platform for Wave Energy Systems and Floating Wind Turbines" dealing with modeling and measurements of motions and the turbine loads of this platform. Before the demonstration platform could be launched, Risø DTU performed a load analysis of the turbines including the platform motions to document that the turbine could withstand the extra loading.

The platform has conducted a five month long test period providing unique knowledge of operation and dynamic behavior of such a type of a floating platform. Furthermore, the measurement campaign has provided a unique database with measured wave and wind characteristic together with platform motion and turbine loads. The modeling effort has resulted in a new simulation tool that combines Risø DTU's well-proven aero-elastic turbine code HAWC2 with DHI's well-proven radiation-diffraction hydrodynamic code WAMSIM, providing a tool that can simulate all different float configurations together with three operating wind turbines. The project continues in 2011 with one more test period and more validation of the new developed simulation code.

APRIL

24

Risø DTU participates in the yearly Festival of Research. The festival is intended to arouse public interest in and enhance public understanding of the methods, processes, and outcome of research and science.

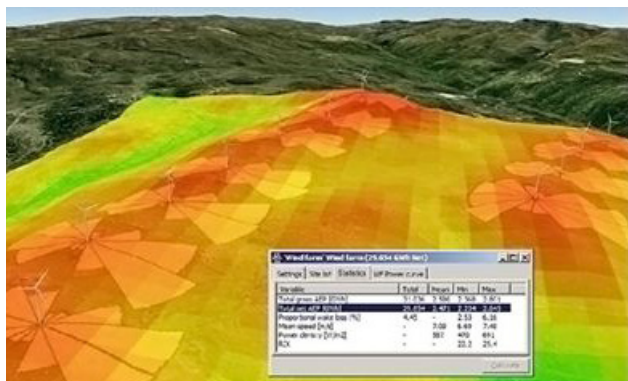
MAY

An area at Risø DTU, equivalent to 20 football fields, is being planted with willow trees. This is the beginning of a new research project aiming to show how a willow plantation impacts greenhouse gas balances. The project also includes an assessment of the overall resource consumption in connection with willow cultivation.



## Meso-Scale and Micro-Scale Modelling in China

For four years, Risø DTU has been involved in mapping the wind resources in the Dongbei region in north-eastern China.

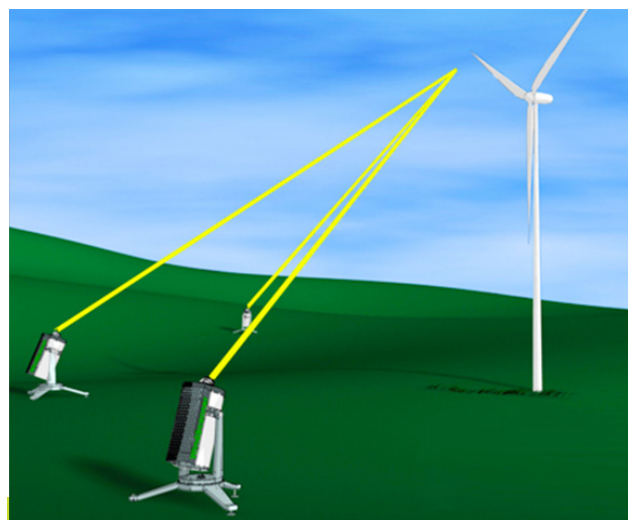


Wind resources in Dongbei have been mapped based on wind data from a number of measuring masts which had been erected for the purpose. Calculations of the wind resources were made using Risø DTU's advanced calculation models.

This work was completed in 2010, and the results are paving the way for planning wind farms in the area with guaranteed high levels of power generation. The work has been carried out within the framework of the Sino-Danish Wind Energy Development Programme (WED). The fundamental idea behind this bilateral development programme is to share with China the experience which Denmark has at incorporating a record share of wind power in the Danish energy system.

## Risø WindScanner part of EU joint research infrastructures

A single WindScanner can produce detailed maps of wind conditions at a wind farm covering several square kilometres. Developed by Risø DTU, the WindScanner consists of high-tech laser systems. It is a sophisticated research facility for studying



The new WindScanner consists of high-tech laser systems, and it can be packed into an ordinary van and taken wherever needed.

wind and turbulence in connection with leading-edge research into wind energy, and it can be packed into an ordinary van and taken wherever needed. The Risø WindScanner will, in collaboration with six European Energy Research Alliance (EERA) partners, be made available to EU's sustainable energy research laboratories and companies via the European research infrastructures.

The European Strategy Forum on Research Infrastructures (ESFRI) has been created to coordinate top-class European research infrastructures. The ESFRI roadmap describes the need for joint European research infrastructures over the next 10-20 years. Following the EU's 2009 call for proposals within the area of sustainable energy, Risø DTU's new WindScanner has been included in ESFRI's roadmap 2010.

## Large test bench to run new Danish wind adventure

In May 2010 Risø DTU and Lindoe Offshore Renewables Center, (LORC) signed a historic cooperation agreement that will ensure the development of the Danish wind turbine industry at sea. The two parties agreed on the establishment of a common test facility at Lindoe, a test bench that will be among the largest in Europe.

The test bench is planned to have a capacity of 20 MW. The cooperation between Risø DTU and LORC ensures access to the test bench for both academia and industry partners - from major wind turbine manufacturers to the small suppliers delivering to the industry.

## Knowledge center for wind turbine components

In 2010 the new knowledge center for wind turbine components was established. The facility will be able to test nacelles up to 1 MW. The idea is to look at the total system from the kinetic energy of the wind to the output into the electric grid. There are influences from both sides and the combination of the two sides increases the complexity. The facility mainly aims at increasing the reliability of wind turbine.

## A new test centre for wind turbines at Østerild

Megawatt-size wind turbines increase in size and it is expected that in the near future it will not be possible to erect the largest wind turbines at the Høvsøre Test Station for Large Wind Turbines due to total height and limitations at Høvsøre. Therefore Risø DTU participates in establishing a new and larger wind turbine test site at Østerild in the Northern part of Jutland.

In June 2010 the legislation came into place, and the new test site is expected to be finalized in 2011. On a more than 4-kilometre-long site, seven mega wind turbines up to 250 metres in height will be erected for testing purposes. Moreover, seven 150-metre-high measuring masts will be constructed to perform measurements on these massive wind turbines, and two 250-metre-high light masts will be constructed and used for meteorological measurements. The Østerild test centre will thus be an important supplement to the Høvsøre Test Station.

The Østerild prototype wind turbine test centre is expected to be something unique in the world that will provide scientists and the wind industry with a wide range of unique test opportunities. Furthermore it's a strong achievement to sustain the Danish leading position in wind energy research.

MAY

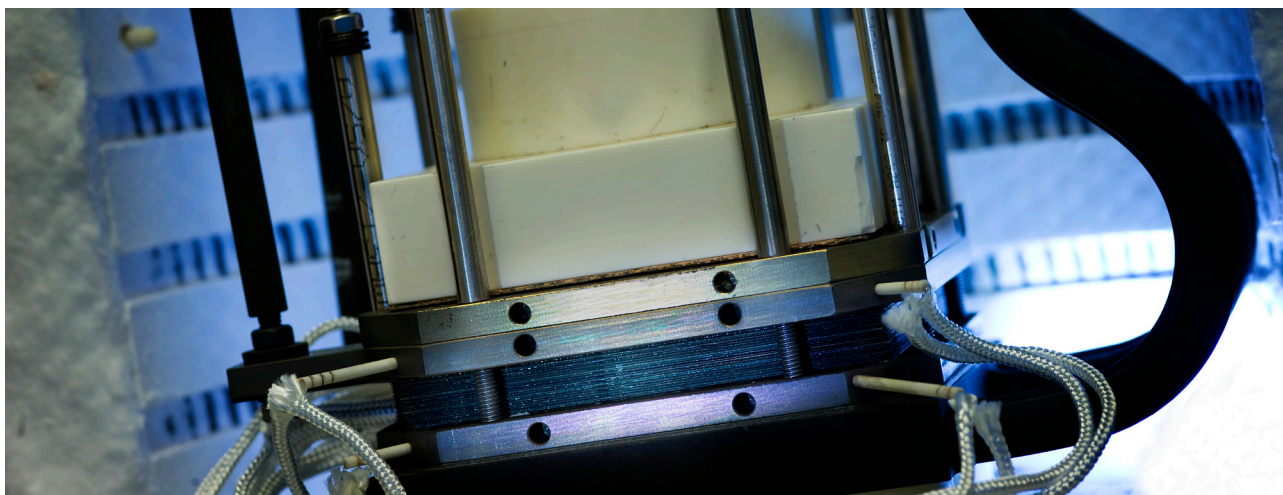
17

Risø DTU course "Validation and process control for electron beam sterilization" is held 17 - 21 May.

MAY

31

Risø DTU holds the PhD course on Soil Carbon, 31 May - 4 June within the framework of STAIR, the International Research Education Program.



## Fuel cells & hydrogen - part of the flexible and efficient energy system

With fuel cells capable of producing energy from hydrogen and other fuels, we have taken a major step forward towards the goal of sustainable energy production. This will have a positive effect on the global environment because it contributes to a reduction of CO<sub>2</sub> emissions and preserves natural resources.

Risø DTU's research into fuel cells and hydrogen contributes to this development. Among other things, we are supplying the basic knowledge for Denmark's production of SOFC fuel cells.

### Solid oxide fuel cells for efficient power production

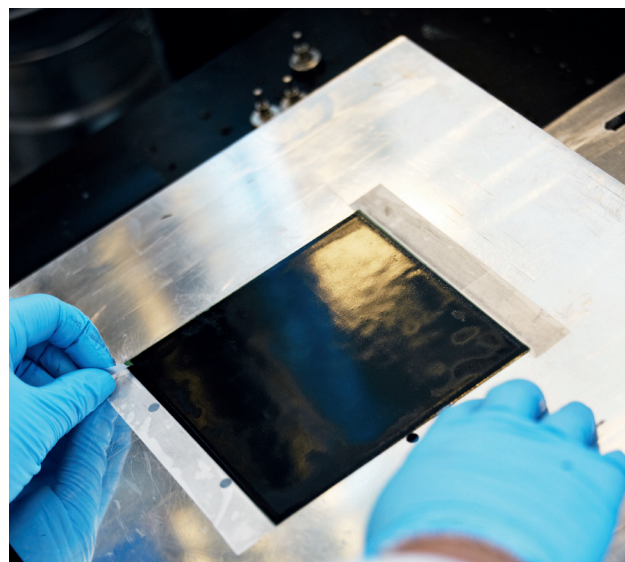
Risø DTU has a longstanding commitment to research and development of solid oxide fuel cells. Such cells can convert the chemical energy of a fuel to electricity with high efficiency. The cells consist of thin active layers of functional ceramic materials supported either by a ceramic or a metallic carrier layer. The research spans all the way from fundamental investigations of electrode performance at the nano-level to the development of industrially relevant manufacturing processes and long term testing of cells to identify degradation mechanisms.

Solid oxide fuel cells have a number of attractive properties, in particular fuel flexibility, high efficiency, low noise and low emissions. Risø DTU has a longstanding close collaboration with the Danish company Topsoe Fuel Cell A/S which has built a pilot plant based on the Risø DTU R&D effort. Together with partners, Topsoe Fuel Cell A/S is deploying fuel cell units in field tests for a number of different applications. In 2010, solid oxide fuel cells based on Risø DTU technology have been tested for use in:

- Micro combined heat and power units – small units which operate on natural gas and produce both power and heat for an individual household.
- Power plants fuelled by landfill gas; a demonstration was carried out in the town of Vaasa in Finland, showing the promise of exploiting the methane gas created when waste is broken down by microorganisms.
- Marine applications; here a 20 kW unit running on methanol was installed on the freighter Undine and operated in real life conditions with good initial results.

### CO<sub>2</sub> neutral transport fuels using high temperature electrolysis

High temperature electrolysis using solid oxide cells is a very promising technology which was created as an offspring of the fuel cell research. By converting electricity to chemical energy stored in a fuel, electrolysis can contribute to the solution of the problem of storing renewable energy. Furthermore, high temperature electrolysis can electrolyse both water and CO<sub>2</sub>,



*A key part of the fuel cell research at Risø DTU is devoted to the study and optimization of up-scalable industrial processes. Here, a functional layer on a cell has been deposited by screen printing.*

#### JUNE

Risø DTU sells Risø TL/OSL luminescence reader number 300. The reader is applied for archaeological and geological dating, retrospective accident dosimetry, detection of irradiated food, luminescence research and is used around the world.

#### JUNE

2

Workshop on "Challenges when Modelling Power Systems with Large Scale Wind Power". It is the third of Risø DTU's Wind Energy Systems Workshop, the first being held in April 2009.



creating a mixture of hydrogen and CO, known as syngas. This is the starting point for well known industrial synthesis processes which can create, e.g., liquid hydrocarbon fuels. In this way, CO<sub>2</sub> neutral transport fuel can be produced from, e.g., wind power. The research and development on solid oxide electrolysis cells at Risø DTU benefit from the extensive competences within fuel cells. Dedicated electrolysis cells are being developed, and we have recently installed test facilities for testing under high pressure; high pressure operation will be crucial for real-world applications.

### Magnetic materials for cooling and heating

Magnetic refrigeration is an emerging technology which uses magnetic solid-state materials together with a non-volatile heat transfer fluid to create energy efficient, low noise cooling or heating. The technology is based on the so-called magneto-caloric effect, which means that certain magnetic materials change their temperature when exposed to a changing magnetic field. Risø DTU has developed a prototype based on a rotating concept which allow high frequency testing. The prototype has shown promising initial results and is presently being tested in detail.

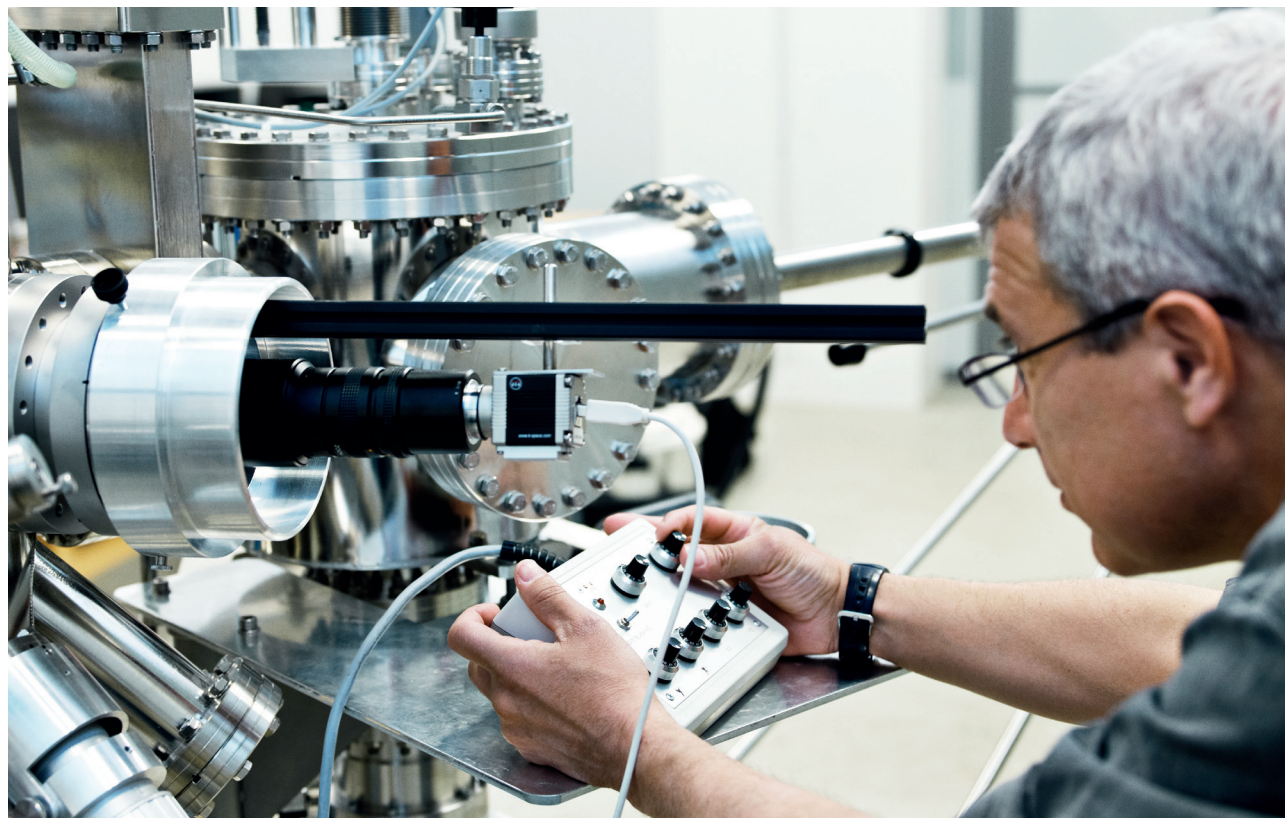
### Thermoelectric oxides for waste heat recovery

A recent activity at Risø DTU within the field of functional ceramics for sustainable energy is thermoelectric oxides. Such materials can convert waste heat to electricity. They work by

generating a voltage in response to a difference in temperatures and as they contain no moving parts they are relatively simple to implement from a systems viewpoint. Thermoelectric oxides will be particularly useful for exploiting diffuse sources of high temperature heat such as arise, e.g., in the cement and steel manufacturing industry. In 2010 Risø DTU developed a novel "p-type" thermoelectric oxide with the world's best performance (a full module consists of both n-type and p-type materials).



*Detailed characterization and testing is essential to develop advanced ceramic components. Unique test facilities ensure that advanced tests can be performed on both individual components, cells and (as shown here) stacks of cells.*



*The largest area pulsed laser deposition (PLD) facility in Northern Europe is located at Risø DTU where it is used to manufacture ceramic layers with a spatial definition down to the nano-scale. Studies of such components advance our understanding of the fundamental processes taking place at this scale.*

JUNE

4

Frederik Krebs is awarded "Ellen and Niels Bjerrums Kemikerpris 2010" in recognition of his work within solar cells and his chemical approach to the challenges within energy technologies.

JUNE

4

European Energy Research Alliance (EERA) launches the first joint European research programmes for sustainable energy and elects Henrik Bindlev, Director of Risø DTU, as new Chairman.



## Bioenergy - a precious, renewable energy source

Biomass is organic matter created through plant photosynthesis with the sun as energy source, i.e. all types of plant material, wood, manure, household waste etc.

Plant biomass can be used both for food for humans, feed for animals and for energy in the form of heat, electricity, gas and liquid fuel. Energy production based on biomass can offer significant environmental benefits by substituting fossil fuels and thus reduce the increase in atmospheric greenhouse gases, particularly CO<sub>2</sub>, and it can contribute to enhanced security of supply.

Risø DTU conducts research in technologies for converting biomass into biofuels and biomaterials.

### Two-stage thermal gasification for combined heat and power

The Two-stage thermal gasification process converting biomass to a combustible gas was developed and tested during 4,000 hours. The results showed high energy efficiency and a good gas quality.

Traditionally thermal gasification gives problems related to tar in the gas, but this specific process is able to produce a nearly tar-free gas. Therefore the gas can be used for many purposes and it has been demonstrated that it can be used as fuel for combined heat and power production with internal combustion engines, for producing liquid fuel (methanol and dimethyl ether) and as fuel for SOFC fuel cells.

In cooperation with COWI A/S and Weiss A/S, up-scaling of the process has taken place and a combined heat and power pilot plant using a gas engine (200 kW electric) has been built and operated with good results. Based on the pilot plant a demonstration plant (500 kW electric) for continuous operation is under construction at Hillerød district heating plant (Denmark).

### Thermal gasification for rural development in India

In India more than 50,000 villages are still without electricity. To change this fact, different rural technologies are under development. One of these technologies is thermal gasification. The goal is to convert residue local woody biomass into a gas which can be used as fuel for a gas engine producing electricity.

In cooperation with The Energy and Resources Institute (TERI) in New Delhi, a small gasifier has been constructed. The gasifier

is combining the advantages of our Two-stage process and a gasification technology developed at TERI.

A pilot plant has been built and tested successfully in New Delhi, and further development is ongoing.

### Plasma Assisted Pretreatment of Wheat Straw

O<sub>3</sub> produced in a low temperature plasma, fed with dried air, was used for the degradation of lignin in wheat straw to optimize the enzymatic hydrolysis and to get more fermentable sugars.

The developed methodology offered the advantage of a simple and relatively fast (0.5 to 1 h) pretreatment allowing a dry matter concentration of 45% - 60%. FTIR (Fourier Transform Infrared spectroscopy) measurements and chemical analysis did not suggest any structural effects on cellulose and hemicellulose by O<sub>3</sub> treatment. Lignin could be removed to 95% from the biomass, and lignin degradation products (30 substances) could be removed by washing and were found in the washing water (carboxylic acids, phenolic compounds). Fermentations with yeast reached the maximum amount of ethanol (10 g ethanol/50 g wheat straw).

If further developed, the described method may be the basis for separation of lignocellulosic material into cellulose, hemicellulose and lignin with the aim to facilitate production of high-value byproducts derived from cellulose based bioethanol production (biorefinery concept).

### Green energy for everybody!

Dry and old pastry, used handkerchiefs, a half-eaten burger, a flat beer – all useless waste? No! Risø DTU has built a mobile low-

JUNE

6

Risø DTU for the first time, 6 - 10 June, holds the course "Medical Radiation Dosimetry". The course provides the theoretical and metrological background for measurement of radiation doses in radiotherapy, diagnostic radiology, and nuclear medicine.

JUNE

7

7 - 11 June, 25 PhD students from different countries are attending a summer school at Risø DTU on remote sensing for wind turbines. The summer school includes practical experiments with remote sensing methods dealing with their advantages and disadvantages.



tech biogas plant and has demonstrated how easy one can turn all the daily leftovers into energy.

In 2010 the simple 1,000 liters digestion tank was presented at events and festivals to promote biogas technology. Visitors were encouraged to contribute with whatever organic material at



*Demonstration at Roskilde Festival of the brand new biogas plant at Risø DTU, where the biogas process was explained to young people at the rock festival in Roskilde.*

hand, crush it in a pedal-driven kitchen blender and feed it into “Denmark’s smallest biogas plant”. In return, one could get a cup of coffee – made on biogas – or just wonder about the little blue flame, which marvelously could be supplied by a tank filled of waste.

The biogas plant concept easily caught people’s interest and many asked with astonishment: “Wow, it’s so easy! Why don’t we have many more biogas plants?”

#### **Low-tech ensiling for combined storage and pre-treatment of energy crops. Back to the roots.**

Via fermentation processes energy crops such as grass clover and maize can be converted to energy in the form of biogas and ethanol. However, a drawback of these technologies is that the production of crops is seasonal and long-term storage often is necessary. Furthermore, some crops require expensive pretreatments before they can be converted to energy.

The conventional way of overcoming such obstacles would be to develop new (sophisticated) methods, but instead Risø DTU

has – with success - gone its own way and revitalized the old low-tech process known as ensiling.

Originally, ensiling is a method for forage storing and preserving and has for a long time been used all over the world. The low pH caused by fermentation of free sugars preserve the feedstock from further degradation by inhibiting fungus microbes, in that way effectively minimizing the degradation of sugars in a crop.

Experiments performed by Risø DTU shows that (as well known) 3 months ensiling of grass clover results in a loss of organic material but it turned out that it also results in a higher biogas production from the remaining material, thus maintaining the overall biogas potential.

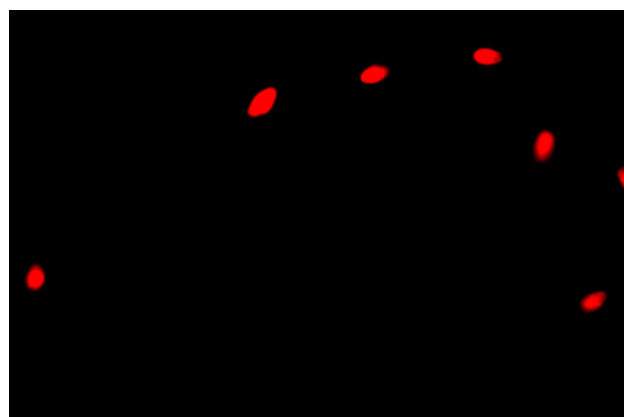
Furthermore, the silage process has been proved to be an efficient wet-storage method which additionally could serve as sterilization and a mild pretreatment method for second generation ethanol from whole crop maize.

#### **Large self-destructing algae for biodiesel**

Some microalgae species found in nature convert solar light and carbon dioxide to lipids, which can be converted into diesel oil using technologies already in use in oil refineries.

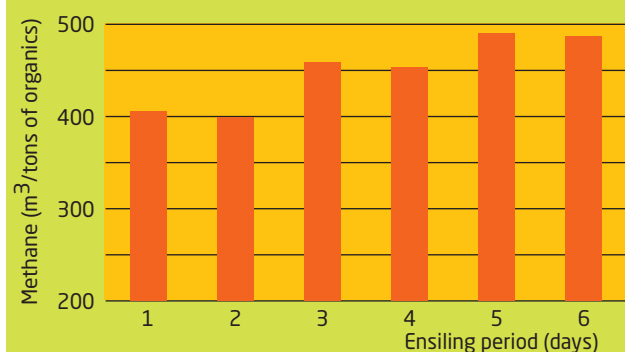
It has already been demonstrated in small scale that microalgae can be grown in waste water enriched with carbon dioxide from flue gas and thus, oil may be produced with the simultaneous cleaning of sewage water. Such plants may already be able to produce oil at a price similar to that of fossil fuels.

Production plants dedicated to large scale production of oil alone are not yet economical, but improved plants and algae can change this. Risø DTU has succeeded in developing mutants of *Chlamydomonas reinhardtii* that overproduce lipids. A particularly promising mutant has cells with an eight fold larger volume and is stuffed with lipid bodies. Temperature elevation results in cell bust and release of lipid bodies easing separation of water and oil.



*Cells of algae (*Dunaliella salina*) induced to synthesize fat that can be used as biofuel. The cells are stained with the fluorescent substance “nile red” and illuminated with UV light. The red color is due to fluorescence from chlorophyll a. The picture on the front cover shows the cells with an additional yellow color due to fluorescence from fat droplets.*

#### **Methane from grass clover. Effect of ensiling**



JUNE

17

The yearly Wind Day, organised by the Danish Research Consortium for Wind Energy, is held at Risø DTU. Wind Day 2010 deals with offshore wind turbines.

JUNE

26

Risø DTU demonstrates sustainable energy solutions at the Roskilde Festival 26 June to 4 July. Among other things, a mini-biogas plant shows the guests at the rock festival how easily one can make energy from their remains of kebab and chips!





## Solar energy - by far the most abundant source of energy

Today solar energy accounts only for a minor fraction of our energy consumption. Our future sustainable and fossil-free society will, however, need to rely on solar energy as one of its major energy sources, simply because the sun is our most abundant source of energy.

Risø DTU develops emerging solar technologies capable of providing energy at a viable cost and in the volume needed for turning photovoltaic into a major contributor to our total energy supply.

### Polymer technology

Polymer solar cells are, unlike conventional solar cells, suited for low-cost mass production. High-speed roll-to-roll printing allows, for example, for processing of as many square meters of polymer solar cells in one hour as a crystalline silicon solar cell plant produces in one year. Risø DTU works actively for realizing this potential and thus turning polymer technology into a winning solar technology when coming to low cost and rapid ramp-up of industrial manufacturing capacity.

### Industrial production capacity

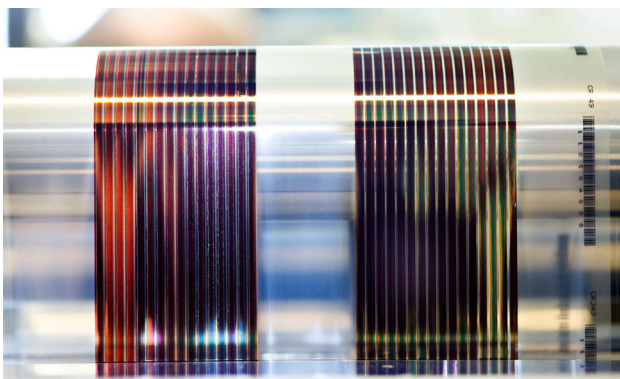
Risø DTU's massive effort in polymer solar technology has, in 2010, successfully been materialized as industrial production capacity. Mekoprint, a Danish supplier of flexprint solutions, has acquired the very first industrial line based upon the Risø DTU's basic process technology. Thanks to EUDP, the Danish Programme for Energy Technology Development and Demonstration, Risø DTU has been able to facilitate this set up at Mekoprint

from A to Z by providing a technology package covering design, manufacturing and installation of the key processing equipment namely the printing head, delivery of all process-specific printing inks, running in, training of the process operators plus engineers.

### Printing in ambient industrial atmosphere

Taking the full advantage of the polymer solar cell's potential for mass production at ultra low cost means no vacuum and no hazardous solvents. Risø DTU's basic process technology relies however on a substrate processed under vacuum and printing inks containing organic solvents.

A break-through in the laboratory, allowed Risø DTU in 2010 to file a patent describing an updated process for which all organic solvents are replaced with water. The patent thus enables important benefits for the working environment and the feed-stock expenditures. 2010 has furthermore brought about highly challenging results in the laboratory guiding the way towards a process without cost-driving use of vacuum.



*Picture to the left shows polymer solar cell manufacturing contains steps with solution processing roll to roll coating of PET film. The active layer, the polymer material that converts photons to electrons, is visible with a dark purple colour with the striped layout typical for roll to roll coating. The pictured solar cell model was with success integrated in 10,000 credit card size LED flashlights in collaboration with Mekoprint for the Organics and Printed Electronics OE-A conference in 2011.*

*The large picture above shows a close up of the in-house developed automatic quality control inline characterization unit for polymer solar cells testing each cell directly on the roll.*

JULY

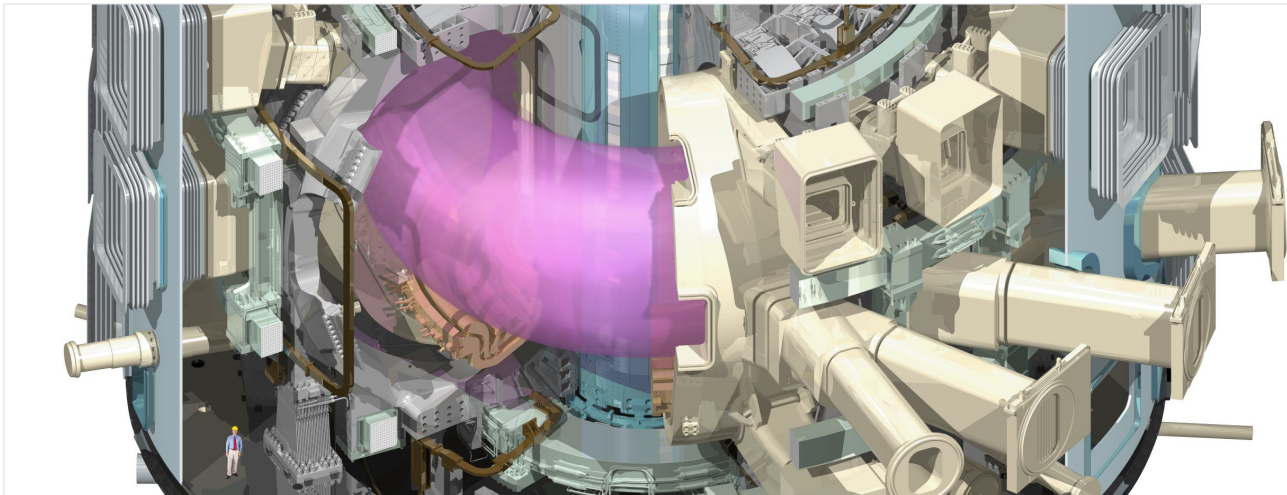
6

Risø DTU holds "Symposium on solid oxide cell electrodes in 3D".

JULY

25

25 – 28 July Risø DTU hosts the 13th workshop on "Targetry and Target Chemistry". The topic of the workshop is the development of new methods for the production of radio-isotopes.



## Fusion energy - tomorrow's inexhaustible energy source

Fusion energy powers our sun and the stars, and is released when light elements as for example deuterium and tritium fuse together. Worldwide coordinated fusion research started in the late 1950s to find ways to use fusion as an energy source here on Earth, and Risø DTU has participated in fusion research since its very beginning, and the effort is an integrated part of the European program through Euratom. This includes participation in the European fusion experiments, as e.g. JET (Joint European Torus).

Fusion energy is a safe form of nuclear energy, which does not pollute the atmosphere with CO<sub>2</sub> and other greenhouse gases. The fundamental "fuels" deuterium and tritium are practically inexhaustible. Deuterium is found abundantly in seawater, and tritium will be produced in the fusion power plant from lithium that is abundant in the crust of the earth. Power plants become radioactive, but the radioactivity will be gone after 100 years, and there will therefore be no need for long-term storage of waste.

### Redistribution of fast ions during sawtooth oscillations

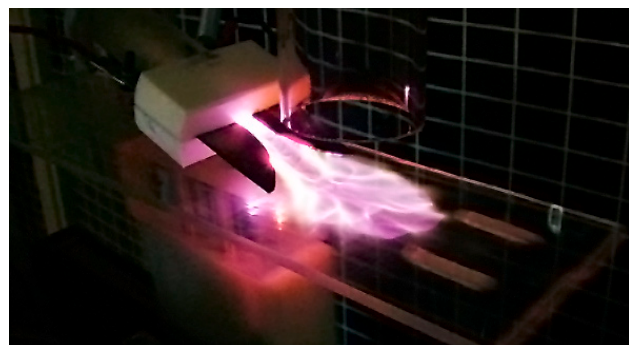
In fusion experiments, plasmas are confined by magnetic fields in a toroidal chamber. Since a plasma consists of charged particles, it may modify the magnetic fields and create plasma instabilities. An example of a plasma instability, which is not yet theoretically understood, is the sawtooth oscillation which owes its name to the resemblance of the time traces of central electron temperature and density with sawteeth. In 2010 Risø DTU has experimentally demonstrated that fast ions in the plasma interact strongly with this oscillation. The measurements show that the level of interaction strongly depends on the angle between the fast ion velocity and the magnetic field. This new observation is expected to trigger developments in the theory of sawtooth oscillations.

### Convection of hot filaments in plasmas

The plasma transport in the edge region of magnetically confined fusion plasmas is mainly carried by coherent filaments. The filaments degrade the confinement and constitute a threat to the plasma facing components. There are strong indications that the ion temperature exceeds the electron temperature in the edge region. In earlier investigations, cold ions were assumed. Risø DTU has investigated the effects of including finite ion temperature into the physical models. When the ion temperature is increased, the filament transport is altered significantly: filaments travel longer, remain compact and the total filament transport is increased by a factor 5.

### Ultrasound enhanced plasma processing

Atmospheric pressure plasma processing has been extensively studied and developed at Risø DTU. One of the highlights in 2010 is ultrasound enhanced plasma processing where we – in collaboration with the University of Southern Denmark, and FORCE Technology – were able to demonstrate that ultrasonic irradiation into the plasma can highly enhance the efficiency of the processing. It is also found that ultrasonic irradiation can suppress undesirable arcing and improve the uniformity of the treatment when it is applied for surface treatment. The technology developed at Risø DTU has already attracted significant industrial interests.



*Gliding arc (atmospheric pressure plasma torch) surface treatment enhanced by ultrasonic irradiation.*

AUGUST

23

Wind Turbine Dynamics and Aeroelasticity - Ph.D. / Advanced eng. Course, 23 – 28 August. The course is aimed at graduate students interested in wind energy research and engineers in the wind turbine industry.

AUGUST

23

Risø DTU holds its course "Validation and Process Control for Low Energy Electron Beam Irradiation" in Ireland, 23 - 25 August. On 22 - 24 March the course was held at Risø DTU.





## Climate and energy systems - sustainable and reliable global energy supply

Globally, three central challenges for the energy systems of the future are emerging: A need for strengthening the security of supply, ensuring reduced emissions of greenhouse gasses so that we can halt climate change, and solutions which contribute to fighting poverty.

Risø DTU contributes to solving these challenges by

- research in and analysis of energy systems and opportunities to support increased integration of wind power and other fluctuating energy sources in the energy network, and
- research into energy policies and energy systems with particular focus on environmental and climatic consequences, including in the developing countries.

### iPower - the Strategic Platform for Innovation and Research in Intelligent Power

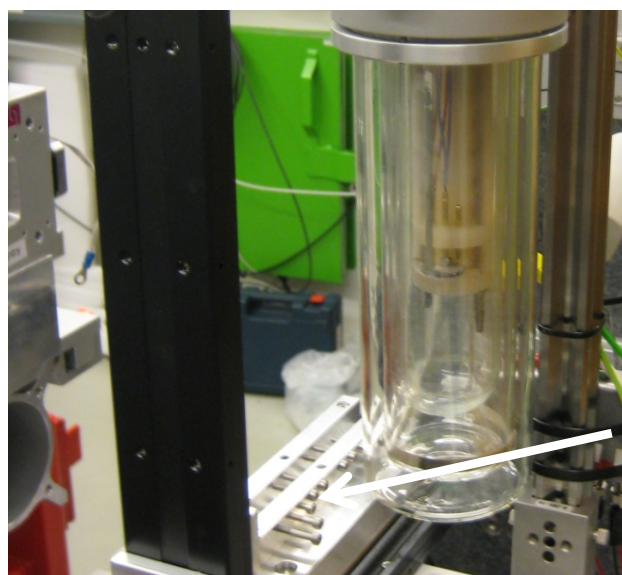
When the wind freshens, our electric appliances must wake up. When the wind drops and produces less power, our electric appliances must go to sleep. But of course in an intelligent and controlled manner so that we can still watch TV, turn on the coffee machine and use the hairdryer. The freezer, however, can easily be switched out a few hours without the pork roast thaws out.

An intelligent power grid - smart grid - that can meet these needs will come up in 2025 when 50% of Denmark's electricity comes from wind energy. This ambition will be met by a new platform called iPower which was established in late 2010 with the aim to develop an intelligent and flexible energy system that can handle the fluctuating power generation. Risø DTU is the coordinator and overall responsible for that the iPower platform achieves the desired results.

The iPower platform is a result of SPIR (Strategic Platform for Innovation and Research), an initiative of the Danish Council for Strategic Research and the Danish Council for Technology and Innovation. iPower gathers 31 partners in a broad national consortium of universities, technological institutions and industry, representing not only 8 major industrial partners but also an significant number of innovative small Danish companies.

### Batteries and carbon free chemical energy storage

As a part of the new theme "Batteries and carbon free chemical energy storage", researchers at Risø DTU and DTU Physics have been working on improving the durability of lithium batter-



*Experimental setup for determination of solid electrolyte conductivity in protected environment at various temperatures. The sample position is shown by the arrow.*

ies by developing new solid electrolytes with improved lithium conductivity. Based on predictions from density functional theory (DFT) calculations, the researchers have synthesized new mixed solid electrolytes, which achieve super-ionic conductivity at battery operating temperatures by stabilizing a high temperature phase of  $\text{LiBH}_4$  at room temperature. By performing partial

SEPTEMBER

6

31st Risø International Symposium on Materials Science: Challenges in materials science and possibilities in 3D and 4D characterization techniques, held at Risø DTU 6–10 September.

SEPTEMBER

13

13–15 September Risø DTU hosts the first annual meeting of the EU supported research project CARBO-Extreme. About 60 researchers from EU, USA and Switzerland meet to discuss their latest findings on how strongly extreme weather events affect the European  $\text{CO}_2$  balance.

substitution of selected elements, the conductivity is increased by orders of magnitude compared to the ground state of pure  $\text{LiBH}_4$ . The electrolytes have been characterized using Electrochemical Impedance Spectroscopy (picture) and X-ray diffraction. A mechanism for the charging of promising lithium-air battery technology has also been proposed.

### Novel electricity market designs

The integration of renewable energy sources into electricity markets can be improved by novel electricity market designs. Traditionally, electricity markets reflect the requirements for fossil-fired generation units. Day-ahead, intraday and balancing markets can be adapted to reflect larger shares of renewable energy sources.

Risø DTU participates in the OPTIMATE, a collaborative research and demonstration project co-funded by the European Commission under the 7th Framework Programme. The project aims at developing a numerical test platform to analyse and to validate new market designs which may allow integrating massive flexible generation dispersed in several regional power markets.

Results in 2010 indicate that improved market timing, complex bid types and new market rules can facilitate a larger uptake of renewable energy technologies. The major part of the analyses are carried out in close collaboration with the German TSO (Transmission System Operator), EnBW Transportnetze AG.

### Analysis, scenarios and counseling

Risø DTU's research in energy systems analysis has been in great demand by authorities and energy companies which needed analysis, scenarios and counseling on economics of new energy technologies, incentives and the impact of various policy instruments.

September 2010, the Danish Commission on Climate Change Policy issued a plan for how all fossil fuels could be dropped in the Danish energy system by 2050. This plan is the most far going strategy for renewable energy deployment in the world, and Risø DTU has played a strong role having a member in the Commission and with the Climate Centre doing the technical work on energy scenarios, cost assessment, modelling of the intelligent energy system, assessment of energy efficiency improvements, and with assessment of policies and measures.

Since the establishment in 2008, the DTU Climate Centre at Risø is also well integrated in project collaboration on climate change impacts and adaptation with leading Danish and international universities and research institutions including work in the newly establish Danish Centre for Regional Change in the Earth System (CRES). A specific task of the Climate Centre is to develop and apply decision support models and cost assessment to climate change adaptation.

The Climate Centre is also involved in global modelling of climate change stabilization targets, energy security, and costs. The focal areas include assessment of sustainable development bioenergy consumptions and climate change mitigation in large fast growing economies such as China and India. The energy modelling work also includes regional studies of air pollution damage costs in the Danish Centre for Energy, Environment and

Health (CEEH).

### International technology transfer and carbon finance

The UNEP Risø Centre on Energy, Climate and Sustainable Development is working at the frontiers of the international climate policy agenda. In 2010 the Technology Needs Assessment (TNA) programme, progressed rapidly with assisting the 15 pilot countries with identification of their technology needs and possible implementation barriers in the areas of both climate change mitigation and adaptation.

A second phase of the program engaging another 21 countries was initiated late 2010. The final products of the program are developments of national Technology Actions Plans by all countries prioritizing technologies, recommending diffusion frameworks, and identifying suitable technology transfer projects and their financial requirements. The program provides a key building block for the new concept of Nationally Appropriate Mitigation Actions (NAMA's) which is currently under development, and is expected to be a vital part of future international climate negotiations.

On Carbon Finance the UNEP Risø Centre has consolidated its leading international position on CDM (Clean Development Mechanism) issues. The Centre has over the last decade provided technical and financial support to more than 40 developing countries and the CDM/JI Pipeline developed by the Centre is used and quoted globally as the major data analysis and information source on Carbon Finance.

In 2010, the pipeline served as the basis for development of a new web-based information platform, the so-called CDM Methodologies and Technologies Selection Tool.

Also, in 2010 the Centre organized - in partnership with UNEP, other UN agencies, the World Bank and private sector organizations - two major regional carbon forums in Latin America and Africa, facilitating the gathering and participation of around 1900 top CDM experts, regulators, CERs (Certified Emission Reduction) buyers and sellers, intermediaries and other service providers of the carbon market.

These carbon forums combine traditional academic conference activities with policy dialogue and stakeholders presentations of existing CDM projects for potential investors.



Visitors at UNEP Risø Centre and UNEP joint stand at Carbon Forum in Africa.

#### OCTOBER

Risø DTU's polymer solar cells have reached a maturity level that allows for demonstrations on a significant scale. To illustrate this, the Polymer Solar Vehicle is demonstrated, a vehicle capable of carrying one person to be powered by polymer solar cells.

#### OCTOBER

21

21 - 29 October Risø DTU hosts the Third International Summit on Organic Photovoltaic Stability (ISOS-3). Workshops are held where researchers test their own active ingredients for polymer solar cells in Risø DTU's large-scale production equipment.





### Climate change will decrease plant production of common crops

Present monitoring of climate change indicators suggests that in this century the temperature increase will exceed the 2°C, which according to Intergovernmental Panel on Climate Change, IPCC, is the critical limit for ecosystem balance, and that a 5-6°C increase might not be unlikely.

Research performed in RERAF, Risø DTU's advanced phytotron for climate change experiments, shows that the yield of barley and oilseed rape will decrease as a result of the combined effects of an elevated temperature of 5°C and a doubling of the CO<sub>2</sub> contents in the atmosphere. This climate scenario mimics the IPCC scenario A1FI. Selection of several cultivars of the two crops for five plant generations at this elevated temperature-CO<sub>2</sub> combination did not significantly increase the yield. So, if adaptation to the changed climate can occur it seems to be a longer lasting process.

The significantly decreased harvest output that we measured in this climate experiment point to future challenges to plant production for food, feed and bioenergy. Next step will be to verify the results in the field under conditions of elevated temperature and CO<sub>2</sub>.

### Nitrous oxide may affect the sustainability of biofuels

Agro-biofuels are expected to reduce CO<sub>2</sub> emissions to the atmosphere since CO<sub>2</sub> emitted during the combustion of the biofuels has recently been assimilated from the atmosphere by the energy crop. However, cultivation of the soil results in emission of other greenhouse gasses, especially nitrous oxide (N<sub>2</sub>O), which is produced by microbes in the soil when the nitrogen availability is high.

Research performed at Risø DTU (BioConcens project) relates measured field emissions of N<sub>2</sub>O to the reduction in fossil fuel-derived CO<sub>2</sub>, which is obtained when energy crops are used for biofuel production. The analysis includes five organically managed crops and three scenarios for conversion of biomass to biofuel.

The results show that biogas produced on either grass-clover

or whole crop maize gave rise to the greatest net reduction in greenhouse gas emissions when the negative effect of N<sub>2</sub>O was taken into account. In contrast, bio-ethanol produced on rye and vetch straw resulted in a rather low greenhouse gas reduction compared to fossil fuels.

Abroad whole crop maize has become increasingly popular as an energy crop for biogas production. Our work suggests that grass-clover is a suitable alternative to maize, and could be a way to increase the diversity of energy crops in the agricultural landscape. Furthermore, grass-clover is a perennial crop and clover plants have the ability to fix atmospheric nitrogen, which minimize energy demanding soil cultivation and the need for fertilizer input.

### Effects of climate change on natural ecosystems

Predictions on future climate change effects in terrestrial ecosystems has generally been based on results from experiments involving in most cases just one or in some cases two climate factors, such as elevated CO<sub>2</sub> and elevated temperature.

In the future, however, terrestrial ecosystems will be exposed



*Emission of N<sub>2</sub>O was measured by manual gas sampling in gas-flux chambers*

#### NOVEMBER

2

Workshop on "Wind power plant control and flexible load management". The workshop deals with the challenges of controlling wind power as conventional power plants, and is the fourth of Risø DTU's Wind Energy Systems Workshop, the first being held in April 2009.

#### NOVEMBER

8

Risø DTU holds "Offshore Wind Energy: Technical Course", 8 – 11 November, for wind energy developers, engineers, scientists and others, working within the field of offshore wind energy.



to simultaneous changes in atmospheric CO<sub>2</sub> concentrations, temperature and precipitation. This has caused concern that the combination of factors could lead to interaction and amplification of the effects compared to the effects of the individual factors.

The Danish CLIMATE experiment exposes a terrestrial ecosystem to all these three main climate change related factors in all possible combination and after 2 years of treatments the results indicate that the combined treatments generally lead to reduced responses (antagonistic responses) compared to exposure to the individual factors. So, there seem not to be indications of so called "run away" effects. It has to be noted that 2 years is a relatively short time, and these results will be supplemented by longer term measurements, which are now being conducted.

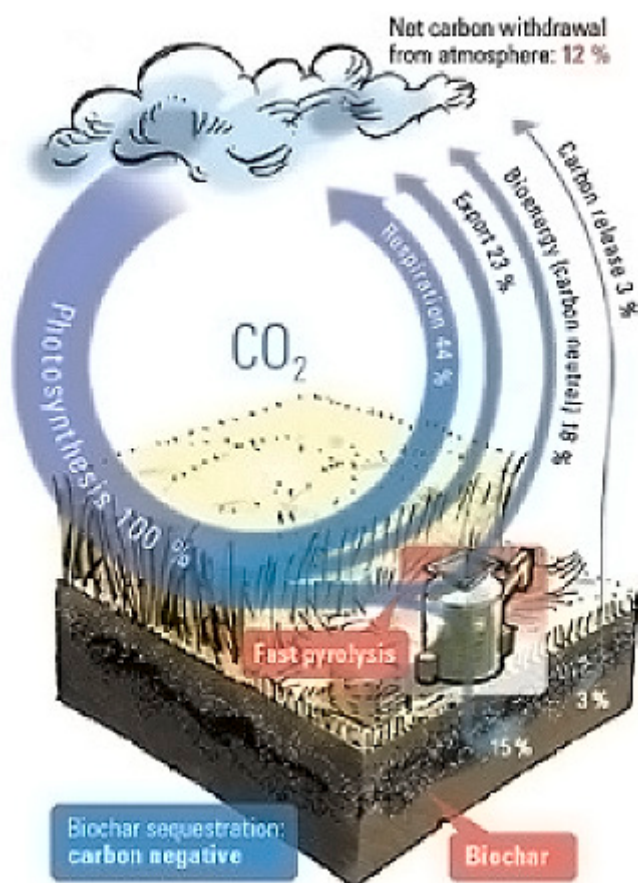
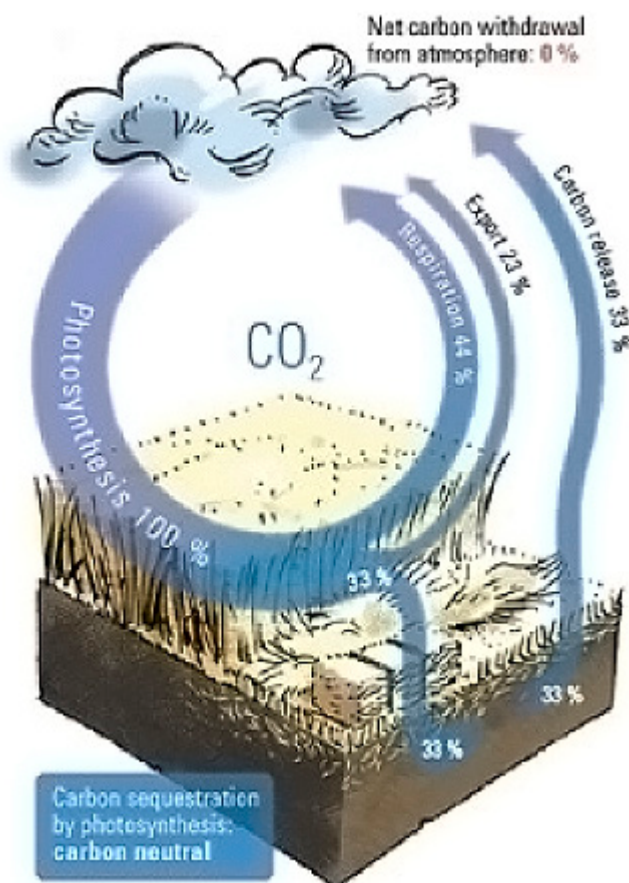
### Soil carbon sequestration and climate change mitigation

Replacing fossil fuel energy production can be obtained by renewable sources such as wind, solar energy or biomass. A further climate change mitigation option is to sequester carbon in soil by application of biochar (charcoal) produced by pyrolysis

of plant biomass. Because of biochar's recalcitrant nature, only a very slow release of the biochar-C occurs, resulting in a long-term removal of C from the atmosphere. In addition, pyrolysis of biomass generates a bio-oil which can be used to replace e.g. heavy fuel oil consumption in a power plant.

Using a fast Pyrolysis Centrifuge Reactor (PCR) developed at DTU Chemical Engineering it has been shown how five PCR reactor temperatures (475, 500, 525, 550 and 575°C) result in the same overall level of carbon mitigation (77-83%) with slightly higher mitigations obtained at the intermediate reactor temperatures. Thus, the pyrolysis concept can be regarded as rather dynamic, giving the possibility to adjust the PCR temperature for either maximized output of bio-oil (525-575°C) or biochar (475-500°C) without reducing the overall mitigation potential of C emissions.

A farmer approach could favor biochar over bio-oil due to the value of applying biochar to the field to improve soil fertility and thereby crop productivity. An alternative strategy for a company investing in pyrolysis facilities would be optimization of bio-oil production due to its market value.



NOVEMBER

9

Risø DTU holds three workshops, 9, 17 and 29 November, that bring together companies and researchers to generate new business ideas and projects, based on bio-refinery.

NOVEMBER

10

Risø DTU holds three workshops, 9, 17 and 29 November, that bring together companies and researchers to generate new business ideas and projects, based on biorefinery.



## Nuclear technologies and ionizing radiation - for the benefit of society

From a historical background within research for the peaceful exploitation of nuclear energy, Risø DTU continues to contribute with research in nuclear technologies and ionizing radiation. Today, focus is on their application in medical sciences, the measurement of radiation dose and in the efficient detection and analysis of radioactive isotopes in environmental samples. In addition, Risø DTU plays a significant role in the national nuclear preparedness programme and radioprotection surveillance. With its activities, Risø DTU continues to expand the opportunities and use of nuclear technologies for the benefit of society.

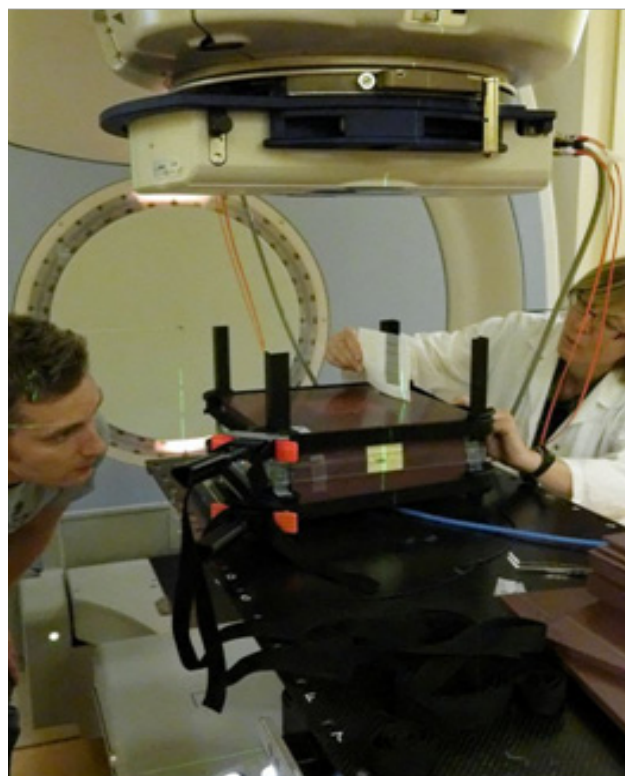
### Dosimetry for radiotherapy

In 2010, collaboration between Risø DTU and Danish hospitals on radiation research expanded. The focus of this collaboration is to develop and apply new dosimetric methods and systems into radiation research for cancer treatment. In particular, Risø DTU collaborates with Rigshospitalet, Copenhagen University Hospital Herlev and Aarhus University Hospital on the assessment of new techniques for radiation oncology.

The medical dosimetry group at Risø DTU participates in these activities with Risø-developed dosimetry systems, in particular using fiber-coupled time-resolved dosimetry with organic scintillators and aluminium oxide, as well as reference dosimetry with alanine. These techniques are aimed at in vivo dose verification in brachytherapy, and new external beam radiotherapy with high spatial and temporal precision.

In the unique Lundbeck CIRRO collaboration (Lundbeck Foundation Centre for Interventional Research in Radiation Oncology) all of the radiation oncology departments at the Danish hospitals along with Risø DTU participate in research aimed at improving individualized radiotherapy and to get the results into clinical practice. Within this collaboration the Risø DTU is heading the dosimetry work program.

In addition, together with the Danish hospitals Risø DTU participates in the education of PhD students and hospital physicist. In 2010 Risø DTU held a new course on medical radiation dosimetry aimed at the education of Danish hospital physicists. The five-day intensive course provided the theoretical and metrological background for measurement of radiation doses in radiotherapy, diagnostic radiology, and nuclear medicine.



*Risø DTU collaborates with Danish hospitals on the assessment of new techniques for radiation oncology. The photo: Radiation dosimetry at Rigshospitalet.*

NOVEMBER

12

Bent Sørensen defends his DSc thesis on "Cohesive laws for assessment of materials failure: Theory, experimental methods and application".

NOVEMBER

15

Risø DTU is the main organizer of "International Workshop on Small Scale Wind Energy for Developing Countries, - Reliability, Materials and Case Studies", held 15 - 17 November in Pokhara, Nepal. The workshop is sponsored by Royal Ministry of Foreign Affairs of Denmark in the framework of the Danish DANIDA program.



### Analysis of ultra-low levels of iodine-129 for geological dating

Risø DTU is collaborating with Chinese colleagues on development and application of nuclear techniques using accelerator mass spectrometry for detection of ultra-low levels of the long-lived radioactive isotope iodine-129 (16 million years half-life).

A procedure of carrier free separation of iodine from low iodine level samples has been developed and successfully tested. This procedure avoids addition of stable iodine carrier which always contains some  $^{129}\text{I}$  and therefore makes it impossible to determine ultra-low levels of  $^{129}\text{I}$  in samples with low total iodine concentrations. The technique can be applied to dating of geological samples in the range 2-70 million years. The Chinese partners are from Xi'an AMS Center, Institute of Earth Environment, Chinese Academy of Sciences.

In 2010 a delegation from Risø DTU visited the AMS center and other organizations in China to discuss cooperation. A visit at the Environmental Radiation Monitoring Center at the Zhejiang Province resulted in the signing of a memorandum of cooperation covering five years involving scientific cooperation, training of staff, information exchange and laboratory intercomparisons.

### Marine science for teenagers

It is often said that young people should forget about computer games and take a greater interest in technical sciences. The project South Baltic WebLab seeks to do something about it. The initiative invites young people into a virtual lab and invites them to yearly science camps.

Universities in countries around the Baltic Sea participate in the project, which is creating interest in marine sciences among young people. The contribution of Risø DTU is to tell about

radioactive substances in the sea which can give information on e.g. how fast sedimentation is taking place on the seabed or, how carbon dioxide from the atmosphere is absorbed by seawater, and how sea currents move around. All factors which are important for climate research.

The initiative comes from Germany and the other participants are from Sweden, Lithuania, Poland and Denmark (Risø DTU). The project runs for 3 years and is supported by EU (European Regional Development Fund, South Baltic Cross-Border Co-operation Programme 2007-2013).



*The science camp in 2010 was a 10 days science cruise around the German island Rügen in the Baltic Sea.*



### The Hevesy Laboratory

A major medical application of nuclear technology is the use of radioisotopes in diagnostics and treatment. At the Hevesy Laboratory at Risø DTU new radioactive pharmaceuticals are developed and produced for the benefit of patients and long-term research in Denmark and abroad.

The Hevesy Laboratory is built on a 50 year long tradition of radioisotope work at Risø DTU, but with strong links and many years of practical experience from national and international Positron Emission Tomography (PET) facilities. The laboratory combines competence in cyclotron and reactor isotope manufacture with radiochemistry.

DECEMBER

16

The architects firm COBE and the consulting engineering firm Ramboll present their vision for how "Risø Park" could look like. "Risø Park" is the working title for Roskilde Municipality's project aiming at establishing a business development park for cleantech, closely connected to Risø DTU.

DECEMBER

20

Troels Friis Pedersen receives the International Electrotechnical Commission's IEC 1906 award for his dedicated and loyal leadership and his persistence in revising standards and ensuring that new technologies are incorporated in the measuring methods.



## Education and training

Risø DTU is deeply involved in education and training, and both university students and participants in Risø DTU's commercial courses come from all over the world, demanding a high quality.

### DTU's MSc program in sustainable energy stays an international success

From the very beginning the Master of Science in Engineering (Sustainable Energy) has attracted both Danish and international students. In 2010, 65 students started on the master, and about half of the new students came from countries other than Denmark. The Master of Science was launched in 2008 and at that time 23 students started their master. In 2009 the number was 35.

### "PhD marketplace"

As a new initiative in 2010, the Risø Energy Day was held. The theme was non-fossil energy technologies in 2050 and beyond, and the event attracted about 190 participants from the energy industry, financial institutions, government bodies, embassies and NGOs. A "PhD marketplace" was one of the elements of Risø Energy Day 2010. About 20 of the PhD students at Risø DTU presented their projects on future sustainable energy technologies and went into dialogue with the participants in the event. Risø DTU gives a high priority to providing PhD students the time and space for in-depth study and as much support as possible. The PhD students are part of daily life at Risø DTU, and his or her research is integrated with the other research being conducted at Risø DTU, and thus he or she makes a difference as a researcher at Risø DTU. At the end of 2010 had a total of 131 PhD students - 56 Danish and 75 from other countries.

### PhD Summer School on advanced measuring equipment for wind turbines

In June 2010, 25 PhD students attended a summer school at Risø DTU on remote sensing for wind turbines. The participants came from many European countries and also from Canada, the USA and Brazil. At the five-day summer school the students learned about the techniques behind remote sensing equipment which has been developed specifically for research in wind ener-

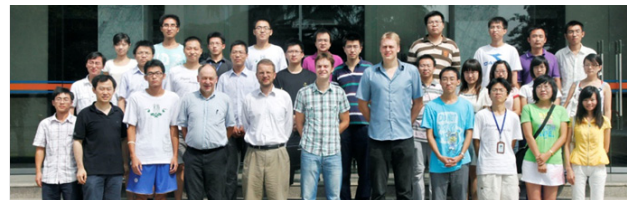
gy. Moreover, they were taught how remote sensing can be used to map wind resources, to measure how much power the wind turbine supplies at certain wind speeds and how to control wind turbines, protecting them from sudden, strong gusts of wind. It was the third year for this summer school to take place.

### New course on medical radiation dosimetry

In June 2010 Risø DTU for the first time held a course on medical dosimetry aimed at the education of Danish hospital physicists. The course 5-day course provides the theoretical and metrological background for measurement of radiation doses in radiotherapy, diagnostic radiology, and nuclear medicine.

### Chinese Danish Autumn Plasma Physics School

The Sino-Danish Centre for Education and Research (SDC) is a collaboration established in April 2010 between Chinese Academy of Science (CAS) and a consortium of Danish Universities including DTU. The "Chinese Danish Autumn Plasma Physics School" was the first educational activity within the Sino-Danish Centre for Education and Research (SDC), and this school was arranged by Risø DTU and CAS Institute of Plasma Physics (ASIPP). More than fifty students took part in the school where five teachers from Risø DTU and six teachers from ASIPP lectured on a range of fusion related topics from neoclassical physics, via the by Risø DTU developed fast ion diagnostics CTS, to technical aspects of the EAST tokamak.



2010 Denmark-China Plasma Physics Autumn School.





## Innovation and business

Risø DTU has a long track record of cooperation with industries, innovation activities and the supply of highly specialized products and services on commercial terms. Through a dedicated innovation activity, Risø DTU has created a systematic process for the transformation of its knowledge into concrete business ideas:

- Building on our technological advancements, we identify and initiate business start-ups.
- In collaboration with industrial partners we address and provide solutions to technological challenges that prevent the creation of new products.
- We undertake specialized assignments on commercial terms.
- We provide specific products, where we have a special expertise.

### Copenhagen Cleantech Cluster

During 2010 the ambitious five year project Copenhagen Cleantech Cluster (CCC) accelerated. The nine CCC-partners are Copenhagen Capacity, The Confederation of Danish Industry (DI), University of Copenhagen, Scion DTU, Symbion, EnergyMap.dk, Business Frederikssund, DHI and Risø DTU. Risø DTU also acts at the entrance to other relevant research competences at DTU (Technical University of Denmark).

CCC was launched September 2009, and in March 2010 networking and idea sharing were on the agenda when Risø DTU and CCC held a preview of the new cluster organisation. Risø DTU is a driving force behind CCC, and the aim of the event was to demonstrate how efforts to match research at DTU with business can help develop Denmark as a cleantech powerhouse.

The event "Tour-de-Risø" was attended by 110 representatives from the business community, researchers and promoters of trade and industry from Denmark and abroad. Afterwards several participants asked Risø DTU for special arrangements or direct cooperation.

"Matchmaking" is one of the three CCC focus areas for Risø DTU, and in 2010 four large arrangements and several meetings between individual companies and researchers at (DTU) were organized.

The other focus area is "Innovation and entrepreneurship" where a number of projects were initiated, and five out of nine planned cleantech PhD scholarships were initiated.

"Test and demonstration" is the third focus area, and here the

work has been concentrated on plans for the establishment of a test and demonstration facility (Demonstratorium). The idea is that businesses in cooperation with scientists at Risø DTU may test both specific technologies and prototypes on a larger scale in interconnected energy systems.

These plans are closely coordinated with Roskilde Municipality's plans for a new business development park with a focus on cleantech technologies, placed very close to Risø DTU.

These plans are closely coordinated with Roskilde Municipality's plans for a new business development park with a focus on cleantech technologies. "Risø Park" is the working title for this project.

The idea is that "Risø Park" is placed on a 50-hectare area east of Risø DTU so that the businesses are close to the research competences, experiments and facilities within sustainable energy.

### Cooperation with Region Zealand (DK) continues

Late 2010 Risø DTU signed a new four year contract with Region Zealand. The aim is to strengthen the region's business community when it comes to innovation and knowledge-based, high-technology development.

The ambition is that thanks to this cooperation Region Zealand will get a few new high-tech-businesses and many more knowledge-intensive workplaces, attract a number of new businesses and that, at the same time, about 100 businesses will increase their innovation and improve their market position.





## Research, development and testing facilities

Energy research and development includes a number of tasks that can only be achieved through the use of large research facilities, and Risø DTU has a number of such facilities.

Also, Risø DTU has bilateral agreements at institutional level and through a qualified staff access to and experience with synchrotrons, reactors and fusion experiment facilities in Europe and the USA, e.g. European Synchrotron Radiation Facility (ESRF), Paul Scherrer Institut (PSI) and Hamburger Synchrotronstrahlungslabor (HASYLAB).

Below is listed some of Risø DTU's research, development and testing facilities.

<b>Experimental Research Facility for Blade Structure</b>	<i>Experimental research facility for full-scale testing of wind turbine blades. The facility will take a blade up to 30-40 metres long and apply combined loading during tests.</i>
<b>Knowledge center for wind turbine components</b> <i>Under construction; expected to be completed in 2011.</i>	<i>A 1 MW wind turbine drive test facility to be used for experimental research covering the components in the wind turbine drive trains. Also the facility will be used for educational purposes and consultancy activities.</i>
<b>Høvsøre Test Station for Large Wind Turbines</b>	<i>Megawatt-size wind turbines are tested, and research projects are carried out on boundary layer meteorology and lidar wind measurements.</i>
<b>Østerild Test Centre for Large Wind Turbines</b> <i>New test site expected to be finalized in 2011</i>	<i>The national test centre at Østerild will provide a site for wind turbines up to 250 metres in height and with a capacity of up to 16 MW and thus supplement Høvsøre Test Station.</i>
<b>Risø Research Facility for Wind Turbines</b>	<i>Six test stands for wind turbines up to 500 kW. For every stand there is a mast equipped to monitor e.g. wind direction, temperature and pressure for the calculation of power. Used for a variety of experiments and research projects, including blade design, and by DTU for educational purposes.</i>
<b>WindScanner.dk and WindScanner.eu</b> <i>WindScanner.eu is since 2010 a part of the ESFRI Roadmap.</i>	<i>Based on recent advances in laser wind measurement techniques. Mobile 3-D remote sensing WindScanner's enables measurement of the "full 3-D picture" of wind and turbulence evolving in space and time.</i>
<b>Risø Meteorology Mast</b>	<i>125 m tall meteorology mast. Wind speed and direction, temperature, humidity and other climate parameters have been measured since 1957. The mast is now heavily instrumented and is used for research disciplines like wind energy, climate change and air pollution.</i>
<b>Facilities for electrochemical testing of fuel cells and electrolytic cells</b>	<i>Test stations for electrochemical testing for short-term, long-term and accelerated testing in controlled environments.</i>
<b>Pulsed laser deposition (PLD) facility</b> <i>In collaboration with DTU Fotonik</i>	<i>Production of ceramic thin films and heterostructures for electrochemical devices such as fuel cells and for electronic components.</i>

<b>Pre-pilot plant for advanced ceramic process technology</b>	<i>Ceramic manufacturing technologies for the fabrication of multilayer electrochemical cells and in particular solid oxide fuel cells. This includes colloidal, shaping and sintering techniques and characterization.</i>
<b>MaxiFuel pilot plant</b>	<i>Co-production of bioethanol, biogas and hydrogen is being studied.</i>
<b>Thermal gasification experimental facilities</b>	<i>Laboratory and pilot plant for thermal gasification of biomass (wood, organic waste etc.).</i>
<b>Polymer solar cell processing facilities</b>	<i>Roll-to-Roll (R2R) coating, screen printing and lamination facilities for all-printed polymer solar cells with in-line testing. Glove box process line for fabricating and testing laboratory scale solar cells in controlled atmosphere.</i>
<b>Polymer solar cell test facilities</b>	<i>Solar cell performance and accelerated testing in controlled environment. Outdoor tracking and concentrator options.</i>
<b>SYSLAB</b> Research facility for intelligent energy systems	<i>Flexible platform for research in advanced control systems and concepts, power system communication and component technologies for distributed power systems. Includes facilities for fast charging experiments on batteries for electrical vehicles.</i>
<b>Brandbjerg (CLIMAITE)</b> Experimental research site to model the Danish ecosystem for the year 2075	<i>Established by CLIMAITE, a Danish research centre to investigate how climatic changes will affect biological processes and natural ecosystems. Center leader: Risø DTU.</i>
<b>Sorø Field Station (Lille Bøgeskov)</b> <i>Proposed as main site for the Danish contribution to ICOS (Integrated Carbon Observation System).</i>	<i>Field station for measurements of greenhouse gas exchange in a beech forest.</i>
<b>RERAF</b> Risø Environmental Risk Assessment Facility	<i>Plant growth facility belonging to a new generation of phytotrons. Experiments can be carried out under fully controlled conditions.</i>
<b>Hevesy Laboratory</b> Radiochemical and radiopharmaceutical facility	<i>Comprises a 16 MeV proton biomedical cyclotron with a beam-line for production of radioisotopes, and two clean rooms complete with hot-cells. Approved by authorities for the development and production of a portfolio of radiopharmaceuticals.</i>
<b>Risø High Dose Reference Laboratory</b>	<i>National Metrology Institute for industrial dosimetry with irradiation facilities for traceable calibration of dosimeters in the dose range 100 Gy - 100 kGy. The facilities comprise 3 cobalt-60 gammacells and an electron accelerator with energy range 80 - 125 keV.</i>
<b>OSL Laboratory</b> Facility for research into the luminescence behavior of natural minerals	<i>Used for all forms of retrospective dosimetry including geological and archaeological dating and accident dosimetry. Includes 21 state of the art automated TL/OSL readers, high resolution gamma spectrometry and sample preparation facilities. The facility is run in close cooperation between Risø DTU and Aarhus University.</i>
<b>Electron microscopes</b>	<i>Electron microscopes comprising different types of transmission, scanning and scanning probe microscopes. Inclusive, the first of its kind Hysitron stage for in-situ mechanical testing in the High Resolution Electron Microscope (HREM).</i>
<b>Laboratory for mechanical testing</b>	<i>Equipped for both uniaxial and multiaxial testing. Accredited by the Danish Accreditation DANAK.</i>
<b>Thermal analysis laboratory</b>	<i>In-situ studies of material properties as they change with temperature, including thermogravimetry, dilatometry, calorimetry and conductivity measurements in the total range of 1700°C, under inert, oxidizing or reducing atmospheres.</i>
<b>Thermometry laboratory</b>	<i>Accredited "in situ" measurements in the range -196 to 1600 K, especially demanding temperature measurements and calibrations in large power plants and incinerators.</i>
<b>X-ray scattering facility</b>	<i>In-situ studies of the structural changes that take place in advanced energy materials. (GI)SAXS and WAXS.</i>



## Publications

Our research results in extensive publication activities through articles in international refereed journals, research reports and other publications. Publications are part of the basis for transferring knowledge and technology to Risø DTU's stakeholders in the political system, industry and research.

Publications 2010	Total number
Scientific articles with referee	410
Books/contributions to books	49
Scientific reports	66
Ph.D. Thesis + Dr. Thesis	28 + 1
Contributions to conference proceedings	170
Other conference and meeting contributions (published abstracts/unpubl. abstracts)	334
Publications for a broader readership	20

Citation impact based on one publication year	
Publication year	Average number of citations
2007 - 2010	11,22
2006 - 2009	8,66
2005 - 2008	8,33
2004 - 2007	8,48
2003 - 2006	8,46
2002 - 2005	7,00
2001 - 2004	8,28
2000 - 2003	7,82

*The table shows the average number of citations for articles published in the first year of a four-year period. E.g. for the period 2007-2010: Average number of citations of articles published in 2007 and cited in 2007-2010. The table is based on Web of Science (Thomson Scientific).*

## CO<sub>2</sub>-free energy can meet the world's energy needs in 2050 (Risø Energy Report 9)

Taken as a whole, energy sources with low or no carbon emissions could easily cover the global energy supply in 2050. This is the main conclusion of Risø Energy Report 9, which was released at Risø Energy Day, 10 November 2010. The challenge for a sustainable global energy system with low carbon emissions will be to use this potential in the energy system the best way possible seen from an economic point of view.

The report lists a wide range of energy technologies in the market with low or no emissions of greenhouse gases, describing how several of these will be made commercially available in the next decades.

There is also a need for a smart grid, connecting production and end use at local level.

Considering the security of supply in the short and long term, there is still a need for access to fossil fuels, but they must be continuously replaced with renewable energy sources. If we do not make efforts to promote renewable energy sources, fossil energy might be prevailing in the global energy supply for the rest of this century.

Seen in isolation, Denmark has a great chance for achieving these goals and for phasing out fossil fuels at a rapid pace and thus reduce emissions of greenhouse gases at the required pace.

Risø Energy Report Series was established in 2002. The yearly reports deal with global, regional and national perspectives on current and future energy issues. Each report is based on internationally recognised scientific material, it is fully referenced and it is refereed by an independent panel of international experts.





#### Mission:

Risø DTU contributes to research, development and international exploitation of sustainable energy technologies, and strengthens economic development in Denmark.

#### Vision:

Risø DTU is one of Europe's leading research laboratories in sustainable energy and is a significant player in nuclear technologies. Risø DTU creates pioneering research results and contributes actively to their exploitation, both in close dialogue with the wider society.

### Management

Director	<i>Anders Bjarklev (acting director since 1 March 2011)</i> <i>Henrik Bindslev (director until 28 February 2011)</i>		
Deputy Director	<i>Lars Martiny</i>		
Head of Biosystems Division	<i>Kim Pilegaard</i>	Head of Radiation Research Division	<i>Sven P. Nielsen (acting)</i>
Head of Fuel Cells & Solid State Chemistry Division	<i>Søren Linderøth</i>	Head of Solar Energy Programme	<i>Peter Sommer-Larsen</i>
Head of Intelligent Energy Systems Programme	<i>Anders Troi</i>	Head of Systems Analysis Division	<i>Hans Larsen</i>
Head of Materials Research Division	<i>Dorte Juul Jensen</i>	Head of Wind Energy Division	<i>Peter Hauge Madsen</i>
Head of Plasma Physics and Technology Programme	<i>Jens Juul Rasmussen</i>		

### Personnel 2010 - FTE

Total number of employees - Full Time Equivalents	663
<i>Of this</i>	
Scientists (VIP)	291
PhD students	101
Other staff (TAP)	271

*Additionally, a number of visiting scientists and master students.*

### Operating statements 2010 (DKK mill.)

Total income	676
<i>Of this</i>	
Basis appropriation	317
Programme activities	230
Market controlled activities	129
Total expenditure	671
<i>Of this</i>	
Salaries	347
Operating expenditures	295
Depreciation	29

Risø DTU is the National Laboratory for Sustainable Energy. Our research focuses on development of energy technologies and systems with minimal impact on climate, and it contributes to innovation, education and policy. Risø DTU has large experimental facilities and interdisciplinary research environments, and includes the national centre for nuclear technologies.

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